

Comment on "Spin relaxation in quantum Hall systems"

In the recent publication [1] the authors have considered the spin relaxation in a 2D quantum Hall system for the filling factor $\nu \simeq 1$. The interest to this system is determined by the fact that the spin relaxation here is due to the collective excitations, the so-called spin-excitons. Thus, correct description requires taking into account the Coulomb interaction and here we deal with the delocalized states. The authors considered only one spin flip mechanism among the three possible [2] spin-orbit related ones. This direct spin-phonon coupling is described by the following term in the Hamiltonian

$$\hat{\mathcal{H}}_{so} = \frac{1}{2} V_0 \hat{\sigma} \cdot \hat{\varphi}; \hat{\varphi}_x = \frac{1}{2} \{u_{xy}, \hat{p}_y\}_+, \quad (1)$$

where $\hat{\mathbf{p}}$ is 2D electron momentum operator, the z-axis coincides with the normal to the 2D plane, $\{, \}_+$ denotes the anticommutator, u_{ij} is the lattice strain tensor due to the acoustic phonons, and $V_0 = 8 \cdot 10^7 \text{ cm/s}$. [3] The authors came to the conclusion that the spin relaxation time due to this mechanism is quite short: around 10^{-10} s at B=10 T (for GaAs) which is much shorter than the typical time (10^{-5} s) obtained in Ref. [4] while considering the spin relaxation of 2D electrons in a quantizing magnetic field without Coulomb interaction and for the same spin-phonon coupling Eq(1). The authors [1] related this fact to the presence of the Coulomb interaction and argued that now they are able to explain the earlier experimental data by M.Dobers et al. I show that their conclusion about the value of the spin-flip time is wrong and have deduced the correct time which is by several orders of magnitude longer. I also discuss the admixture mechanism [2] of the spin-orbit interaction. The authors [1] obtained the following expression for the spin-relaxation rate:

$$\frac{1}{\tau_{so}} = \sum_{\mathbf{Q}, i=x,y} \frac{\pi}{2\hbar} |\lambda^i(\mathbf{Q})|^2 \delta(E_{ex}(q) - \hbar\omega_Q), \quad (2)$$

where $\mathbf{Q} = (\mathbf{q}, Q_z)$ and ω_Q are the phonon wave vector and the dispersion law, $E_{ex}(q)$ is the 2D dispersion law for the spin-excitons, $\lambda(\mathbf{Q})$ is the constant which couples the projected spin density of the electrons and phonon creation operator in the electron-phonon part of the second-quantized Hamiltonian. Using Eq.(1), we get: $|\lambda^i(\mathbf{Q})|^2 = (\hbar^3 V_0^2 / 32 \rho s Q) q^2 q_i^2 \exp(-q^2 l_B^2 / 2) |\Lambda|^2$, where $\Lambda(Q_z) = \int dz \chi_0^2(z) \exp(iQ_z z)$, s is the sound velocity, ρ the crystal mass density, l_B the magnetic length and χ_0 is the wave function in the z-direction. Note that parameter $x_0 = (\hbar s / \epsilon_c l_B)^2 \simeq m s^2 / E_B \approx 5 \cdot 10^{-4}$ in GaAs, here $\epsilon_c = e^2 / \kappa l_B$, E_B are the Coulomb and Bohr energies. Then the main contribution in Eq.(2) comes from $Q_z \simeq \epsilon_c / \hbar s \gg q \simeq 1 / l_B$ and we obtain: $1 / \tau_{so} \simeq (0.48 \sqrt{2} / 4 \pi^{3/2}) (V_0 / s)^2 (\hbar / \rho l_B^5) x_0^{1/2}$. The estimate for GaAs at B=10 T gives $\tau_{so} \approx 4 \cdot 10^{-5} \text{ s}$ (we assumed $\Lambda = 1$ which can only overestimate the rate).

It is much more essential, that with taking into account the *spin-independent* interaction with the phonons the energy relaxation time is much shorter than the spin relaxation time and realistic situation corresponds to the spin relaxation of the 2D electron system which has the lowest possible energy [5]. Then the characteristic energy transferred to the phonon during the spin-flip transition is much smaller than ϵ_c which appeared in Eq.(2). Now it is determined by Zeeman energy Δ or temperature T . (It remains unclear why the authors [1] who assumed the temperature of the electron system to be much smaller than Δ , obtained Eq.(2)). Two different physical situations are possible [5] depending on the degree of excitation of the spin system (i.e. the number of the spin-excitons created in the 2D system). If this number is macroscopically large (exceeds some critical value $N_c \propto T$), then the dominating channel of the spin relaxation is the annihilation of two "zero" (i.e. with $q = 0$) excitons from the condensate with simultaneous generation of a "nonzero" exciton and phonon. The interaction with the phonons was spin-independent but the spin-orbit term in the Hamiltonian $\beta(-\hat{\sigma}_x \hat{p}_x + \hat{\sigma}_y \hat{p}_y)$ which is due to the absence of the inversion symmetry in the crystal cell leads to an admixture of the state with the opposite spin and allows spin-flip transition [2]. The non-exponential relaxation of the S_z component is described by exactly the same equation as that obtained in Ref. [1] but with time (for the interaction with piezo-phonons) $1/\tau_0 \simeq (\Delta M s^2 M \beta^2 / \hbar^3 \omega_c^2) ((e h_{14})^2 / \hbar s^3 \rho)$, which is written for $T, M s^2 \ll \Delta$. Here h_{14} is the piezomodulus and M the exciton mass. This time does not depend on the magnetic field and is $10^{-5} \div 10^{-6} \text{ s}$ depending on β . The mechanism described by Eq.(1) gives a much smaller contribution to the rate. In the case of $N \ll N_c$ or near equilibrium when the main process is a direct recombination of the "nonzero" excitons, the spin relaxation rate is proportional to the temperature and can be also relatively small (time is longer than 10^{-6} s for $T < 1 \text{ K}$) [5].

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